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Principle Investigator: Ray Hyman, Professor of Psychology 686-4910 Area Code 503

Co-Investigators: Barry Anderson (8/3/67 to 8/31/68)
Fred Attneave
Jacob Beck (9/1/70 to 8/31/71)
Richard W. Haller
Douglas L. Hintzman (6/15/69 to 8/31/71)
Steven W. Keele
Michael I. Posner
Gerald M. Reicher
Benson Schaeffer
Wayne A. Wickelgren (8/1/69 to 8/31/71)

Title: **CODING SYSTEMS IN PERCEPTION AND COGNITION**

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13. ABSTRACT

This contract was established to study experimentally the different ways that human subjects represent information and how these forms of representation facilitate or hinder adaptive behavior with respect to environmental information. This problem was seen as especially important in today's world because the new technology has resulted in an information "explosion" in almost every field of endeavor. In military, as well as civilian situations, more elaborate and more sophisticated devices bring ever increasing amounts of information to human operators who, on the basis of this information, must operate equipment or vehicles or must make important decisions that frequently have life and death consequences. No matter how much better and how much more information is delivered to the human decision maker, the new technology conveys no advantages if the human is unable to make use of this information. Research on human performance has clearly indicated how limited is man's capacity for dealing with information. He must selectively react; he cannot cope with it all. The work on this contract provides information that might be relevant to this issue by bringing to bear different subareas of experimental psychology--perception, psychophysics, memory, thinking, psycholinguistics, motor skills, and human performance--upon the common problem of coding systems and their interactions with each other and with inputs and outputs.

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SUMMARY

The contract on "Coding systems in cognition and perception" was established to experimentally study the different ways that humans represent information and how these forms of representation facilitated or hindered adaptive behavior with respect to environmental information. This problem was seen as especially important in today's world because the new technology has resulted in an information "explosion" in almost every field of endeavor. In military, as well as civilian situations, more elaborate and more sophisticated devices bring ever increasing amounts of information to human operators who, on the basis of this information, must operate equipment or vehicles or must make important decisions that frequently have life and death consequences. No matter how much better and how much more information is delivered to the human decision maker, the new technology conveys no advantages if the human is unable to make use of this information. Research on human performance has clearly indicated how limited is man's capacity for dealing with information. He must selectively react; he cannot cope with it all. The work on this contract was intended to provide information that might be relevant to this issue by bringing to bear different subareas of experimental psychology--perception, psychophysics, memory, thinking, psycholinguistics, motor skills, and human performance-upon the common problem of coding systems and their interactions with each other and with inputs and outputs.

The major methodological accomplishment was the development of an efficient and fully operating automated laboratory. About 75% of the research done on this contract was done with the aid of this facility. The automated laboratory is built around two computers--a PDP-9 and a PDP-15--which are mated. Along with these central processors and related peripheral equipment, which were purchased under the contract, we developed the necessary software to conduct a variety of experiments and to time-share effectively. The development of the laboratory is described in more detail in a special section of this report.

The program was quite successful in experimentally isolating and investigating several different coding systems employed by humans in storing, retrieving and acting upon information. In the perceptual area, for example, we were able to marshall lines of converging evidence to demonstrate the existence of a Cartesian-like internal reference system which enables the perceiver to preprocess information in a way to make it simpler for later contact with memory. In the memory area, we have in several different ways, clearly demonstrated visual, articulatory, auditory and semantic principles of organization which are independant or quasi-independent of one another. In addition, there seem to be kinesthetic memory systems which operate independent of the central processing system. We have made beginnings in specifying important properties of these systems as well as their interrelationships to each other. Our work on these systems and the highlights of our findings are described in the section on research findings.

The work on this contract concentrated on isolating and examining the properties of different representational systems. This work lays a firm foundation for the next steps which will emphasize the growth, development, and change in representational systems during adaptive behavior. The practical implications come from the possibility that the different systems each have their optimal range of applications and the combined use of different systems may be the key way for humans to overcome inherent limitations of their processing systems.

TABLE OF CONTENTS

1.0. INTRODUCTION AND OVERVIEW

Our original application to do research on this contract, which was submitted in 1966 began with the following words:

"The proposal deals with the interaction between coding systems and stimulus events in perceptual and cognitive tasks. This interaction is viewed as a reciprocal relation between the form of the coding system and the characteristics of the stimulus event. On the one hand, we want to investigate the ways in which the characteristics of the coding system are determined by the qualities and organization of components in the stimulus event. On the other hand, we want to study how the efficiency with which an individual operates upon the stimulus information is determined by the characteristics of the coding system which he employs in the situation. The general plan is to attack this issue by means of a series of different, but closely coordinated, research projects. The projects will individually investigate the same problem from a variety of different viewpoints--form perception, multidimensional psychophysics, scaling, decison and choice theory, concept learning, skill learning, inductive logic, and problem solving. We will coordinate the projects by means of several devices: 1) the formulation and application of a common terminology, notation, and system of concepts; 2) the use of identical stimulus sets; 3) the use of common tasks, dependent variables, equipment, and experimental designs; 4) the rotation of research assistants among projects; and 5) a single individual as principal investigator who has the authority to decide, at each choice point, whether a given experiment does or does not directly contribute to the overall goal of helping us understand how the characteristics of a coding system affect an individual's ability to use information in perceptual and cognitive tasks."

This report is technically the final report of how well we met our objectives during the four years of the contract. Compared with our initial expectations of five years ago, we feel that we have more than surpassed our original hopes. One reason for this was that we originally contemplated a nucleus of six investigators. But this quickly grew to 10 main investigators in addition to a Visiting Scholar. This alone gave our manpower more than a 50% increment over what we had planned. A second reason was the gratifying, but unexpected, success in developing an automated laboratory near the end of the first year of the project.

This report is the "final" one in a legal sense only. Because of the inevitable lag in publication, in preparing results for publication, and bringing incompleted studies to a conclusion, not all the research findings and publications that eventually will be credited to this contract can be reported so soon after the expiration of the contract. At this time we cannot be sure of the final tally of such work. Consequently, the principal investigator plans to spend next summer in preparing a more integrated, and hopefully, more complete final version of our accomplishments.

N. Moray

1968-69

Adrian de Groot

Lee Brooks

Wolfgang Metzger

C. Coombs

D. Hintzman

W. Wickelgren

1969-70

P.M.A. Rabbitt

B. Julesz

D. Mackay

1971-72

R. Gottsdanker

G. Rizzolatti

R. Shepard

H. H. Clark

M. Tatham

A final, but very important activity, was the offering of courses each year and every summer on using the laboratory computer. This was primarily intended to prepare our investigators and research assistants to use the automated laboratory in an efficient manner. But many other individuals came to take our courses in order to learn this important new way to conduct experiments.

1.3. Personnel

During the four year period the contract supported the work of 11 different main investigators, all of whom were members of the Department of Psychology at the University of Oregon. Seven of these investigators were on the contract during its four year duration. The others were on for varying lengths of time as indicated on the cover page.

The contract also at one time or another supported the work of five other postdoctoral fellows. The two main Visiting Scholars were H. K. Beller (two years) and Carlo Umilta (one year). Joe Lewis served as the director of

1.1. Accomplishments

The results of our research as reported in our various publications (see the Bibliography of these attached to this report) are our most obvious accomplishments on this contract. A less obvious, and somewhat remote accomplishment will be an integrated summary of these accomplishments. Some of our own publications or ones in preparation already go a good way towards achieving this latter goal. Good illustrations would be a book on "Attention and Human Performance" being completed by Steve Keele and book, in preparation, by Michael Posner on memory and thought. And, of course, the more complete report which will be written by this principal investigator this summer is another illustration.

The last section of this report summarizes the highlights of our research. These are reported by individual investigators, rather than by subject matter. Also, under each investigator is covered the principal findings from theses, dissertations and other research done by students or colleagues under his supervision. The investigators themselves are organized into subgroups which broadly and loosely designate their major area of focus: perception and psychophysics; cognitive processes; and human performance. Such an arrangement by investigators is convenient at this time, but in a more integrated report, the arrangement will be by topics and subject matter. The complete details of the various studies can be found in the reprints of the published papers; those which are available at the time of this final report are being submitted with it.

Another major accomplishment is in the area of methodology. Actually, our work resulted in several methodological breakthroughs. For the most part these are described in the last section or in the accompanying reprints. Our key accomplishment in this area, however, has been our automated laboratory. This is described in a separate section of this report.

1.2. Other activities

In addition to the research publications and the automated laboratory, many other activities were undertaken in connection with this contract. Seminars were offered on the goals and findings. Many students were trained in our laboratories while doing research on the contract. Several of these students completed Masters Theses and Doctoral Dissertations while doing projects for the contract. All the investigators and many of the students gave talks on their work at major professional meetings and at other universities.

We used some of our money to bring in consultants from other major laboratories to keep ourselves informed of relevant work being done elsewhere. A listing of these consultants by the year of the contract is given below:

1967-68

H. P. Bahrick

G. Sperling

T. Trabasso

L. Horowitz

our laboratory for one year after his doctorate. Ernie Adams and Manard Stewart spent one or more summers working on our contract.

All told, 16 different investigators beyond the doctorate contributed to the work on this contract.

A total of 39 graduate research assistants and 15 undergraduate research assistants also worked, at one time or another, on the contract (not all at once).

In addition the contract supported entirely, or in part, 15 completed doctoral dissertations and 13 completed Masters Theses. Several other independent research projects by graduate students and undergraduate students, when they were directly relevant to the project, were supported by the contract. These will be reported in the last section of the report.

In addition to graduate and undergraduate research assistants, the contract supported a technical staff that consisted of 2-1/2 secretaries, 5 research assistants (not all concurrently employed), a systems-analyst programmer, an electronic technician and three part-time technicians.

1.4. Output

At the time of the writing of this final report, the contract had resulted in 54 papers published or in press. Another 20 or so have been submitted for publication or are being prepared for submission. If we add to this total theses and dissertations not yet published or submitted for publication, then we come up with a figure of approximately 90 independent experiments or experimental projects completed under the four years of the contract. This figure is an underestimate since many projects, especially ones started during the final year of the contract, are still not completed or have not been analysed and evaluated as yet. Many of these, given the inevitable lags inherent in laboratory research, will undoubtedly result in publications which will be credited to the present contract. Therefore, the final count of published work on behalf of this contract will certainly be well over 100 separate papers.

This figure of 100 publications, of course, refers only to research that was directly supported by the contract. Indirectly, the work on the contract already has had widespread ramifications and will continue to do so for some time to come. Already there are 15 former students, graduates of our program, who are continuing the type of research that they learned to do while working in our laboratory. These former students are continuing our type of work in over a dozen different laboratories in this country and Canada. In addition, our Visiting Scholars are also continuing to do the work for which they were trained in our laboratory (this adds at least Italy as one of our outposts). We assume several of the students who are still working towards their doctorate and who have worked on the contract will also continue this dissemination of our work And much of the outcome from the first four years, methods, new ideas, findings, and the like will continue to influence the work here at Oregon of the investigators and their future students. The automated laboratory, which stands as one of the most important legacies of the contract, will continue to support research of the type we emphasized during the contract years.

1.5. Applications

Because our contract was to conduct basic research on coding systems, our chief product is knowledge. This knowledge, for the most part is embodied in the form of written documents--publications in professional journals, chapters in books, theses, technical reports, etc. Such an output of documents, each containing several statements or conclusions, is one basis for assessing the yield of our combined efforts on this contract. But a more satisfying basis for judging our success will be the extent to which we can organize this huge list of statements into coherent and cross-referenced form so that it is accessible to various agencies and individuals. This final report is only a first step towards this latter goal. We hope to digest and integrate the findings from our contract into a more complete and unified report sometime after the contract expiration and this report has been submitted.

Because we are experimental psychologists, this integrated system of statements about human coding systems will not be a manual of instructions which can be immedietely applied to the solution of specific problems. But we hope that it will be a useful guide to people and individuals who do want specific advice on how to apply knowledge about coding systems to specific situations in which a human has to process information.

In one sense we should have greater aspirations about the potential applicability of our findings from this contract than we would from findings from other areas of basic research in psychology. Most traditional areas of psychology generate research in response to problems that were originally generated by philosophers and other academics. There is little a priori reason to expect that answers to such problems will have obvious applications to practical situations. In contrast, the information processing approach to psychology, which is the approach of the work on this contract, arose in response to very practical problems during World War II and its aftermath. These problems had to do with questions involving man-machine interactions and with problems of how to arrange displays and environments such that man could best cope with the ever increasing amounts of information that the newer technology was flooding upon him. Consequently, our paradigms and laboratory situations are often simulations of real-life situations in which humans have to react quickly or accurately on the basis of information displayed on a variety of devices. We would be surprised if there were not some obvious applications of some of our work even without intermediate developmental stages. In fact, we have already seen some of our findings put to practical use in designing type faces for maps, in developing programs for teaching correct pronunciation of new languages, in finding better ways to diagnose deficits in mental retardation and brain damage, and in measuring the more subtle, but probably more meaningful, effects of environmental pollution such as those on an individuals ability to handle information in a rational and efficient manner.

During the last year of the project we began new work in applying our findings to such problems as the efficiency of reading, the effects of environmental noise on information processing, the development of new ability tests based upon the isolable components and processes that we have isolated in our laboratory, the basis for high-level skills such as those displayed by experts in various fields, and similar problems.

2.0. THE AUTOMATED LABORATORY

The Automated Laboratory began in April, 1968, with the acquisition of an 8K PDP-9 computer and associated peripherals (2 dectape units high-speed, paper tape) including an oscilloscope and light pen for displays at a total cost of $42,250. To facilitate the rapid and smooth integration of the computer system into the lab, a faculty member with experience with experimental use of small computers, a systems programmer and a computer technician were hired prior to delivery of the system. After installation was completed, an 18 bit digital input system was implemented for interfacing key press responses and a millisecond accuracy clock for timing response latencies. Actual experimental use of the computer was then able to begin within two weeks of installation.

The next step taken was to make the system more available to the average user by implementing a standard set of machine language subroutines callable by Fortran programs which made it possible for the Fortran user to write programs which utilized the non-standard real-time devices (i.e., the experimental apparatus). Use expanded greatly at this point. Meanwhile an additional oscilloscope, a Tektronix 611, was interfaced. It provided a much larger format (8" x 11" instead of a circular 5") and provided for larger displays since it was a storage scope and did not require "refreshing." Also, a digital output system was implemented allowing control of such devices as lights, in-line display cells, noise generators and eventually tape-recorders. Once again, Fortran callable subroutines for their operation were provided.

By Winter, 1968, usage had increased to the point that it became obvious that demand for computer time would soon outstrip supply. The solution decided upon was to implement a simple multiprogramming time-sharing system to allow two experiments to run at the same time. Necessary hardware additions including a swapping timer and all the interfaces for a second experiment were begun concurrently with software development. The resulting system underwent a gradual evolution, but by Fall, 1969, a stable, reliable time-sharing system was in operation and experiments were being run simultaneously. The work involved included modifying standard DEC software to make it smaller, rewriting many DEC and home systems programs to make them sharable by the two users (especially the Dectape handler) as well as the time-sharing monitor itself.

A major drawback to this system (called Son of Zoroaster 4) was the relatively small amount of space available to the users. This severely limited the combinations of programs that would fit and reduced the amount of time two users were actually running. This was alleviated to some extent with a major modification which overlaid part of the resident system and freed extra space for users. At this point it became obvious that demand would once again outstrip supply. Since a newer version of the PDP-9, the PDP-15, had since become available, and it was more suitable for developing larger time-sharing systems, and since the cost was about the same as enlarging the 9, we decided to purchase a 12K PDP-15. It was delivered in July, 1970 at a total cost of $50,000 including an interprocessor buffer which allows communication between the 9 and the 15 at memory cycle speeds. The latter has proven valuable to us as it allows one computer to "eaves-drop" on the other for purposes of monitoring its behavior--particularly the accuracy of its timing of events, a critical question for most of our experiments.

Since the instruction code of the 15 is a superset of the 9, it was easy to transfer all our previous work to it, so single experiments began immediately. An even more major drawback of SOZ4 was the fact that both users had to be loaded simultaneously. If something happened to one program it was necessary to stop the whole system and reload. Likewise, different experiments at one station could not overlap with the same one at the other without reloading. A decision was made to implement a more flexible system on the 15. The structure of the computer suggested giving each user 4K of core and the system (including sharable programs) 4K. This would allow a total of seven users (since the maximum core size of a normal 15 is 32K). Hence the name Pleides. A hardware memory protection system was implemented to prevent one user from interfering with another. Pleides began running two experiments simultaneously in October, 1971. The full system including an editor and assembler available to the user in his 4K to allow program development concurrently with experiments is projected for February, 1972.

The initial Pleides was built around the concept of a response station. A response station consists of 4K of core, a teletype, a dectape unit, and necessary experimental apparatus (scope, digital I/O for switches and lights). A response station costs $13,420. This is, to be sure, just about the same price as one would pay for a single 4K mini-computer with similar experimental apparatus attached. However, the power of the time-sharing system is considerably greater. For example, the user has access to mass storage for I/O, file oriented I/O, and a sophisticated monitor which speeds and simplifies his experimentation. Such a system would require an additional 4K for each separate computer, substantially increasing the cost (anywhere from $4-6,000).

Current Plans for Development

So far one of the greatest barriers to more widespread use of the computers is the amount of programming effort involved in either implementing a new experiment, or in some cases, modifying an existing one. This stems mainly from the relative unsuitability of either Fortran or machine language for describing psychological experiments. We are currently implementing a higher level language, called Experiment Writer. EW is interactive, and allows the psychologist to describe his experiment to the computer in terms he is familiar with (e.g., "trial", "block", "show", "wait", "accept"). EW then outputs some code which is executed interpretively by another program Experiment Runner. Presently this system is limited in capability. It can only present stimuli via the scope and accept key press responses. It does not provide feedback to the subject or summary statistics for the experimenter. Such extensions are planned for the future. This system should allow even experimenters with no background in computing to "program" an experiment with about 15 minutes of introduction to the system.

We expect that the past growth in use of our automated laboratory to continue. This past rate has been about one experimental station per year. Unfortunately although we possess the hardware and software capacity to continue to meet such needs for several years to come, we have reached a limit in actual physical space available for experimental stations at our current location. If, as we expect, the development of EW both speeds up the rate of programming and entices people who currently do not use the system to use it, the future rate of growth will actually exceed the past and the backlog

at our current site will become overwhelming. Plans for the Straub Hall site have been designed to optimize use of the computers, not only by providing convenient locations for additional stations, but for easy connection of other experimental rooms to the computer for purposes of data acquisition, but not experimental control. Pleides has been designed to allow an unlimited number of "lines" to be attached to the computer. When a switch attached to a line is closed, Pleides records a time for that line since the last closure. This is output on paper tape. At the end of the day a special program will separate the accumulated data into separate files for each line on Dectape which can then be analyzed either on the 15 or 9 or the central PDP-10 time-sharing system. In this way an experiment can be facilitated without necessitating a full station. For many, full experimental control by the computer is unnecessary and this data collection facility is sufficient.

We might add that an additional benefit expected from the Straub site is increased quietness. The sound isolation at our current site is not very good, and as a result some of the benefits derived from the more precious and accurate control of experiments provided by the computer are being lost.

Educational Role of the Computer

So far the presence of the computer has had a dramatic effect on many of our graduate students. Several of them (e.g., Steve Boies, Joe Lewis, and Nancy Frost) have played key roles in the development of the facility. One got a job with IBM on the basis of his experience; and the attractiveness of the others to psychology departments was definitely enhanced judging from the fact that they were given direct responsibility for developing similar systems at the universities which hired them. Even those students who did not become as intimately involved with the computers as the aforementioned have benefitted greatly from their experience and will be better equipped to compete in a research environment which is becoming increasingly computerized.

We have recently begun to integrate our computers into undergraduate instruction on a more formal basis (at least three undergraduates have become proficient in their use on an individual basis, designing, programming and running their own experiments on the computer). We expect that the implementation of EW will greatly facilitate this process.

3.0. RESULTS OF RESEARCH

The organization of this section is by areas and investigators within areas. Our investigators or postdoctoral scholars break into three natural groupings: perception and psychophysics, cognitive processes, and human performance. In a crude way these areas correspond to emphasis upon input processes, central processes (including storage and retrieval), and output processes. The dividing lines are determined by emphasis; almost all the investigators overlap one or both other areas in their work and interests. Indeed, it is this overlap which make for integrative possibilities on our project.

Under each investigator we have also described those students whose theses or doctoral dissertation they supervised. In some cases students did a Masters Thesis with one investigator and the doctoral dissertation with another.

In such cases the students work is completely described under one investigator, usually the one he was last supervised by. Quite frequently, the supervised work belongs more naturally in one of the other two areas. But we describe this under the investigator section to emphasize how much overlap there was among the projects. Furthermore, one of the stated goals of the contract was to rotate students among investigators and projects and such discrepancies between the supervisor's area and that of his student illustrates the extent to which we achieved this objective.

3.1. Perception and psychophysics

This area includes Attneave, Beck, Fagot and Hyman.

FRED ATTNEAVE

Attneave's work on our project has focussed upon how we represent physical space. The emerging picture, based upon his work, is that such a representation is analog rather than digital in character. His papers on tridimensionality (Attneave and Frost, 1969), spatial coding (Attneave and Benson, 1969), and similarity grouping (Olson and Attneave, 1970) imply an internal model of physical space which is analog in nature and which may be primarily visual in character. Such an analog coding system, obeying a minimal principal, complements the type of coding systems that we have studied in the cognitive and performance areas. In Attneave's work, the emphasis is on the type of perceptual economics that operates to simplify perceptual input before contact is made with memory. The work in the other areas focusses upon the economics involved after contact is made with memory or during the process of making this contact.

Attneave's work on tridimensionality not only contributes new conceptual insights and empirical findings about the nature of perceptual organization, but it also represents a new breakthrough in methodology (this methodology has already been used to good advantage in the doctoral dissertation by R. K. Olson which will be mentioned below). In these experiments on perceived tridimensional orientation, the subject aligns a rod in three dimensions (which he views with both eyes) to correspond with the perceived slope of the edge of a two-dimensional line-drawing of a box-like figure (which he views with one eye). The results are consistent with the existence of an internal spatial coding system in which distances in all directions are interchangeable (isotropy). From such experiments a model of how a subject's percept is formed can be roughly sketched as follows. From sort of an iconic, two-dimensional input the lines of the drawing are projected into a three-dimensional (internal) spatial schema. From an infinite number of possible projections, the perceptual system achieves, by means of a hill-climbing method, a three-dimensional representation that minimizes the complexity of the percept. In this particular experiment, one possibility is that the subject achieves a representation such that the lines forming the edges of the box are parallel and of equal length and such that the angles between lines would be the same. A cube, for example, would be much simpler to encode than most two-dimensional projections of a cube because the three-dimensional representation enables the subject to deal with only one length of side and one angle between sides. Once the perceptual system has achieved a projection that is minimally complex in terms

of "descriptors", these descriptors, in turn, are used to make contact with memory in order to identify or otherwise deal with the stabilized perceptual form. This account, of course, simplifies the actual situation. In the more complete picture we must allow for various feedback loops between memory or meanings, descriptors, and spatial representation. Within the more complex system it makes sense to ask questions about the role of prior expectancy and labelling upon the minimization forces that are working at the preprocessing level, etc.

This model with its relationships between descriptors, stimulus arrays and an internal Cartesian reference system promises to integrate a diverse range of previously discrete perceptual phenomena. Attneave has already shown its relevance to problems of similarity grouping (Olson and Attneave, 1970), perceived tri-dimensionality, reversing and ambiguous figures, and spatial location.

Attneave's work on pitch (Attneave and Olson, 1971) also makes a major methodological contribution along with its substantive findings on pitch discrimination. In this study, Attneave and Olson were concerned with the nature of the invariance involved in pattern equivalence under transposition. Coding of tonal patterns, at least in long-term memory, seems to be based almost entirely on <u>relations</u> between pitches; however, it appears that whereas naive subjects tend to represent these relations in quantitative or analog form (remembering the <u>size</u> of an interval), musically sophisticated subjects represent them in a categorical or digital form, remembering the <u>identity</u> of an interval for which they have a definite pigeon-hole.

R. K. Olson (now Assistant Professor of Psychology at the University of Colorado), under Attneave's supervision, completed his doctoral dissertation on "The role of shape variables in the trapezoidal window illusion" (1970). His results strongly support the role of shape variables in the illusion of oscillation. The plane of apparent reversal varied with both height-width ratio and linear perspective.

Robert Frost (now at the University of Washington) also completed under Attneave's supervision his doctoral dissertation on "Constancy of perceived spatial relationships on a surface viewed at a slant" (1971). Frost started with a classical problem of shape constancy. When a two-dimensional form is seen on a surface, the constancy of its shape is remarkably invariant despite changes in the slant of the surface with respect to the observer. Ordinarily, such constancy of spatial components has been dealt with as a function of the shape, itself. Frost's dissertation studied to what extent such variables as extent, tilt, and angle can sustain perceptual constancy when the shape context has been removed. Constancy seems to apply to spatial variables, then, judged in isolation from a perceived overall shape. This dissertation reveals another extension of Attneave's ideas on an internal Cartesian representational system.

Frost also carried out other research projects while working on our project. His study "On the convergence of apparently vertical straight lines" (1971) used dwarfs and extremely tall subjects as an ingenious way to test an implication of some theoretical speculations made by Helmholz in his <u>Physiological Optics</u>. And his study with C. Snyder "Stimulus localization and attention in a reaction time paradigm" (1970) was an attempt to clarify the way that perceived spatial locus enters into the identification and attentional demands of a stimulus.

JACOB BECK

Beck became a co-investigator on our project during its final year. Only part of Beck's work in the area of perception overlaps with our focus on coding systems and it is just this part which we have agreed to support. The study with Johnson and Stevens "An after effect of apparent movement" is currently being replicated and a paper will be prepared soon after.

W. H. Eichelman (now at the University of Massachusetts) completed under Beck's supervision his doctoral dissertation "Changes in the relative discriminability of slant and configuration differences" (1970). Eichelman began with the findings from previous studies that perceptual grouping and visual search depend for their success upon the type as well as the degree of difference between the target and the background (non-target stimuli). In a series of experiments, Eichelman had his subjects determine whether a target was present in the field or not. He examined combinations of three variables: (1) eccentricity of the figure with respect to the fixation point, (2) uncertainty of where a figure will be presented in the visual field, and (3) the number of non-target figures presented in the field. He interpreted his results in terms of Neisser's (1967) distinction between pre-attentive and focal-attentive processes. When the position of a target is not known and cannot be detected on the basis of gross brightness differences (when background figures are present in the display) pre-attentive processes are used to identify the figure presented. These processes are maximally sensitive to simple kinds of differences regardless of the degree of difference, e.g., slant, brightness, motion, etc.

Eichelman completed his Master's Thesis "Letters as units of processing in a visual matching task" (1968) as well as the paper on stimulus and response repetition (1970) under Posner's supervision. The Masters Thesis is one of the few demonstrations that familiarity can enhance the early stages of processing concerned with physical characteristics instead of just the later stages concerned with memory contact. In the study on stimulus and response repetition, Eichelman showed how the repetition effect was more a matter of stimulus repetition at very short response-stimulus intervals but became more a matter of response repetition at longer intervals. He also developed a model to relate the work on matching of letters with that of repetition effects in serial and discrete reaction time tasks.

ROBERT F. FAGOT

Fagot and his students contributed to the overall goals of the project by developing measurement and formal models to provide us with both the language and axiomatic tests for dealing more precisely with the coding systems we have been isolating. During the summers, Professor Ernie Adams of the philosophy department at the University of California, Berkeley, has joined our project to collaborate with Fagot on the axiomatic formulation of these models (Adams and Fagot, 1970; Adams, 1972).

Both Fagot's experimental and theoretical work feeds into our general work on coding systems in a variety of ways. He and Adams have emphasized those parameters of models which have a psychological interpretation. One type of parameter often can be interpreted as a "response bias" (Fagot and Stewart, 1970). Fagot and his collaborators have shown that, once such "bias" is measured and removed, rather exacting tests can be made between alternative

models. With such corrections, many subjects who are quite consistent can be separated out from subjects who violate assumptions because of irreparable inconsistency. Hyman, for one, has been able to use such corrections to focus upon "well-calibrated" subjects in obtaining psychological spaces within which judgments of similarity are made.

Fagot has shown that interval models based on an additive law generate data that are more reasonable and internally consistent with axioms of measurement than do ratio models based on product laws (Fagot and Stewart, 1969). This has had important implications on other work on the project when the investigator would like subjective judgments of the magnitude of the stimulus elements within a system. It turns out that we are more likely to derive consistent scales from subjects by asking them to report directly on differences between stimuli on given magnitude scales rather than on positions of individual stimuli on these same scales (the typical magnitude estimation task). This result is far from intuitively obvious, yet it already has resulted in much improved data in our judgment work.

During the last year of the project, Fagot was working upon an operational theory of interval measurement which would permit response bias parameters. At the same time he was working on the axiomatic structure of numerical response methods (such as S. S. Stevens magnitude and ratio methods, as well as comparable methods utilizing only interval information). His work continued at the empirical level to test these models.

Under Fagot's supervision, Menard Stewart (now at the University of Northern Illinois) completed his doctoral dissertation on "Memory and absolute judgment" (1969). His results support the idea that subjects judge a stimulus on the basis of a temporary store which includes the preceding few stimulus exposures. But this support only holds for the first half of his experiment. With subjects who were well practiced in the situation, the model no longer held. One possibility is that with much practice, the subject can construct a more stable, long-term coding system within which to locate a stimulus and need no longer depend upon his store of immediately preceding stimulus traces.

In addition to collaborating with Fagot on several studies, Stewart made valuable contributions to the development of our automated laboratory. One of these contributions was the development of a PDP-9 plotting package which enables an experimenter to rotate figures on the Cathode tube. This package has been put to use in several studies in the cognitive area.

Both R. Kleinknecht (1971) and K. Murdoff (1971) completed Masters Theses which, in different ways, added additional tests and information for evaluating the psychophysical models being developed by Fagot.

RAY HYMAN

Hyman and his students have concentrated on projects that deliberately try to combine the coding systems implied in the perceptual experiments of, say, Attneave, and those implied in the matching and performance experiments of, say, Posner. Hyman's project on pattern recognition, for example, attempts to deal with performance in a task in terms that employ Posner's concept of an abstract idea or schema and Attneave's concept of an internalized Cartesian framework. Posner and Keele (Posner and Keele, 1970; Posner, 1970) employed a classification task in which the subject had to learn what category each of

a small set of exemplars belonged to. In theory, they could learn the appropriate category for each exemplar by rote, or they could abstract out a single schema or surrogate from the exemplars that belong to the same category and employ this single surrogate as their basis for judging future patterns. The experiments of Posner and Keele supported the schema model. The schema model, in turn, implies a coding or representational system that has combined digital and analog properties. The subject presumably constructs and stores a small set of discrete, qualitatively different surrogates to stand for each category. When the subject is presented with a new pattern to put into one of the given categories, he compares the new pattern with each of his stored surrogates and classifies the pattern according to its similarity to each of the surrogates. The classifications into categories imply a digital system that sorts objects into discrete types. The basis for deciding if a given pattern is sufficiently similar to a category schema, however, implies an analog system that evaluates distance in a continuous space.

The coding schemes that underly the work of Attneave and the earlier work by Hyman and Well on similarity judgments, are completely analog in nature. They imply a continuous space within which exemplars, surrogates--if any, and new patterns are considered as points whose location is specified by values on a set of coordinates which defines the space.

Hyman devised a pattern recognition task that would enable him to simultaneously consider the schema-type and the spatial type coding systems. The exemplars and test patterns for any one subject were always systematic variations of a single random-9-dot pattern. The exemplars and test patterns differed from each other only in height and width (affine transformations). The subjects were never told the basis for the variations among patterns and, for the most part, most did not realize the dimensional basis along which the patterns differed either throughout the experiment or at least during the acquisition stage. In all the experiments a simple rule differentiated patterns belonging to each of the two categories--patterns belonging to category "A" were higher than wide and patterns belonging to category "B" were wider than high. Subjects learned to classify patterns as A or B on the basis of 4 exemplars per category or of 6 exemplars per category. Then they were tested, without feedback, for their ability to classify 24 patterns, including the original exemplars. The dependent variable was the speed as well as the accuracy of the classification.

Three basic models were devised to explain the classifications. Two models belong to the stimulus-generalization family. These two models envision that subjects handle new patterns by comparing them with stored representations. The Averaged Distance Model assumes that a subject develops a separate representation for each exemplar. Each test pattern is then compared with all the stored representations for each category. The test pattern is classified into that category from which its averaged difference from all the exemplars is least. The Prototype Model assumes that the subject, during learning, constructs a single surrogate or prototype to stand for the set of exemplars belonging to a category. He then classifies a test pattern in terms of which of these stored prototypes it is closer to. Both the Averaged Distance and the Prototype Models are called stimulus generalization models because new patterns are judged in terms of closeness, in a Euclidean space, to stored representations. A spatial or Distinctive Features Model assumes

that the subject, during learning or even later during testing, abstracts out the dimensions along which the patterns can be discriminated (distinctive features) and then develops a *rule* for classifying patterns based on these dimensions (e.g., classify all patterns that appear taller than wide as A's).

Each of these models generates different predictions about which of the 24 test patterns should be recognized with shortest latencies. Hyman's theory was that these models were not mutually exclusive but, rather, described different *stages* of mastery of the classification task. During the first few trials of acquisition, the subject was seen as trying to store a separate representation (description) of each exemplar. At a later stage, (especially in conditions where there were 6 exemplars), the subject would develop a composite representation for the category. At a later stage, even during the testing phase, the subject might "realize" that all the patterns can be economically characterized in terms of two coordinates.

The results on one completed experiment indicated that the 4-exemplar conditions were consistent with the Averaged Distance Model. But when subjects had to learn to classify patterns on the basis of 6-exemplars per category, the Averaged Distance Model gave way to one of the other two models. Presumably this was because it was no longer feasible for the subject to store separate representations of each exemplar. For subjects getting one pattern, the Distinctive Feature Model was the best fit; for subjects getting another pattern, the Prototype Model provided the best fit. Because of the variability among individual subjects, we could not assess transitions from one model to another, if such took place, within the data of single subjects. Also, there is some doubt about the group whose best fit was the Distinctive Features Model. Only two of the five subjects, when examined individually, had best fits to the Distinctive Features Model. Because of this, we are currently replicating this study and also adding some additional conditions to further determine if any subjects actually ever achieve the distinctive features level. The one clear finding is that when the exemplars are increased, at least for one pattern, the Prototype Model clearly becomes the best of the three (all five subjects in that condition clearly fit the Prototype Model better than the other two).

Hyman and his students began a series of studies combining aesthetic preferences for patterns with pattern recognition, memory, and judgments of complexity. Rogers and Hyman (Rogers and Hyman, 1971) have completed some preliminary experiments in which auditory patterns and their visual analogues have been studied both separately and in combination. They have found the usual inverted U-shape preference function relating preference to complexity for the auditory patterns. But the yoked visual analogues produce, instead, a monotonically increasing function of preference on complexity. We are currently relating this finding to possible differences in short-term memory for visual and auditory sequences. The eventual goal is to use the relationships among preference, memory, and pattern learning as another way of operationally determining the appropriate model to describe what subjects are doing when they classify patterns.

Hyman and Reicher conducted a series of preliminary studies to see how feasible it might be to apply our laboratory techniques on coding systems to

studying problems of reading, especially speed reading. We have employed some theory from transformational grammar as well as the matching procedures developed during this contract. We have also begun to develop ways to measure just what poor and good readers are extracting from material that they are reading under normal and under speed-up conditions. So far our progress has not been great, but we plan to continue. We feel that we have overcome at least some of the big hurdles that confront anyone who tries to rigorously examine comprehension and reading speed.

Arnold Well (now at the University of Massachusetts) completed under Hyman's direction his doctoral dissertation on "The influence of irrelevant information on speeded classification tasks" (Well, 1969 and 1971). Several studies have shown that when irrelevant information is added to stimuli, it can effectively be gated--i.e., there is no increase in RT. However, in some cases RT increases with the addition of irrelevant information. Well studied situations in which one might get imperfect filtering.

One notion has been that dimensions that were previously relevant for the task, but are now irrelevant, will interfere with RT because the previously relevant stimuli call for competing responses. In two different experiments Well found no evidence at all for the notion of learned competing responses. Lack of perfect filtering in his situation did not appear to depend upon whether an irrelevant dimension had been previously relevant in the same task.

A second notion has been that irrelevant dimensions interfere primarily when values on the relevant dimension are hard to discriminate. Support for that hypothesis had been demonstrated, for example, by Morgan and Alluisi. Well clearly found evidence that the addition of irrelevant dimensions interferes primarily when the values of the relevant dimensions are hard to discriminate. Well suggests that the imperfect gating of irrelevant material may be a function of the particular attributes that are relevant and irrelevant and their interrelationships. Some dimensions that can be formally varied independent of one another are not perceptually independent and, from a psychological viewpoint, the "irrelevant" variations may not be truly irrelevant (for example, increasing the size of targets can be done independently of their physical brightness, but not of their apparent brightness).

George Atwood (now at the State University of New Jersey, Rutgers) completed under Hyman's supervision his doctoral dissertation on "Experimental studies of Mnemonic Visualization" (Atwood, 1969 and 1971). This dissertation was awarded honorable mention in the American Institute of Research's annual Creative Talent Awards. Atwood focussed upon a series of questions aimed at gaining information about the nature of imagery and its operation in mnemonic systems. The key question was, "Does the mnemonic image involve the visual system directly?" In approaching this task, he adapted some of the techniques and findings of Lee Brooks at McMaster's University. In one experiment, Atwood was able to show that an irrelevant visual perception interferes more with verbal learning by means of imagery than does an irrelevant auditory perception. In a crucial second experiment, he was able to demonstrate that the relative interfering effects of these perceptions were reversed in a verbal learning task which did not involve visual imagery. The mnemonic image is apparently a process occuring at some level of the visual system. On the basis

of these and other experiments Atwood devised a theoretical model of cognition in which a visual system is distinguished from a verbal-auditory system. The visual system controls visual perception, spatial representation, and visual imagination. The verbal-auditory system controls auditory perception, auditory imagination, internal verbal representation, and speech. Attention can be more efficiently divided between the two systems than within either one taken by itself.

Under Hyman's supervision, Nancy Frost (now at the University of Washington) completed her Master's Thesis on "Clustering in the free recall of pictorial material" (N. Frost, 1970 and 1971) and her doctoral dissertation on "Interaction of visual and semantic codes in memory" (N. Frost, 1971). The Masters Thesis is the first experimental evidence known to us that clearly demonstrates that clustering in free recall can take place in terms of purely visual instead of semantic or verbal attributes.

Nancy Frost's doctoral dissertation focussed upon the interaction of semantic and visual attributes in the organization of memory. Her results indicated that subjects store both semantic and visual attributes of a stimulus and can retrieve these attributes in parallel; the mode of retrieval, however, depends upon whether the subjects expected to be tested for recognition or recall. Under recall instructions the subjects apparently retrieve information only by semantic tags, even though subsequent tests reveal they have also stored visual information. Under recognition instructions, subjects retrieve items both in terms of visual and semantic attributes.

Also under Hyman's supervision, Jeaneatte Silveira completed her doctoral dissertation on "The role of incubation in problem solving," 1971. Silveira first demonstrated that interrupting a subject while he was solving a problem could increase the probability of a solution provided that the interruption did not come too soon. She also studied the effects of varying the length of the interruption period. The heart of her dissertation, however, was an intensive analysis of just what aspects of the total process had been altered during the interruption. The hope was that a sufficiently detailed codification of the protocols might suggest the particular ways in which the interruption produces its affects as well as provide clues as to whether the effects were due to forgetting, recovery from fatigue, or active processing during the interruption. The analysis of the protocols revealed that the interruption does not affect the amount of work the subject does, the amount of blocking he expresses, the number of new ideas or directions, nor the amount of perseveration. The interruption may prevent a decline in overall quality of problem processing. However, the major qualitative affect of the interruption is to change the content of the subject's thoughts. Interrupted subjects concentrate their ideas in the correct direction and they make more abstract statements correctly delineating the area of search. The results argue strongly against a forgetting hypothesis and somewhat less strongly against a fatigue hypothesis. A possible reminiscence hypothesis is suggested. The major contribution of this dissertation, in our opinion, is that it represents the first real breakthrough in experimentally analyzing an important, but previously elusive, aspect of problem solving.

Bernia Corrigan and Hyman have conducted a series of experiments to determine the conditions, if any, under which independent variations in dimensions can result in additive increments in transmitted information during absolute judgment tasks. As a corollary, they have studied the conditions under which subjects treat uncorrelated dimensions as correlated (and thus

transmit systematic error). To fully analyze this work requires new theoretical and simulated analyses of information transmission measures to find ways of removing biases. Corrigan has been conducting this work and developing new computer programs for checking it out. Some of this work may eventuate into his doctoral dissertation. Corrigan has also made some contributions to our automated laboratory, especially in developing programs for better communication between our mated PDP-15 and PDP-9. Some of this latter work is being submitted for publication.

3.2 Cognitive Processes

This area includes Barry Anderson, Richard Haller, Douglas Hintzman, Gerald Reicher, Benson Schaeffer, Wayne Wickelgren, and our Visiting Scholar H. K. Beller.

BARRY F. ANDERSON

Because Anderson (who is now at Portland State University) was a co-investigator on our project only during its first year, he did not complete some of the work that he had started on comparing perceptual with conceptual abstraction. His student William L. Johnson (now at Whitworth College), however, did complete his doctoral dissertation based on Anderson's work (Johnson, 1968). Anderson had used as his basic stimulus material a string of black and white squares. He felt that black and white squares would tend to form perceptual units so that runs of black or white would be taken and processed as single elements. Their data supported this hypothesis. The number of black cells within a sequence of black cells (all adjacent) were processed in parallel, perhaps by some kind of area or brightness estimating process. However, the separate runs of black cells appear to be searched in series--for every run of black cells there is an increment in time to match the two stimuli.

In his doctoral dissertation, Johnson's basic idea was that subjects will match runs of cells on the basis of brightness when two strings are simultaneously present in the perceptual field. But, as a time interval is interposed between one string and the other, he expected the subject to develop some kind of code which will abstract certain aspects of the location of the runs. He predicted that the major determinant of a 'different' reaction time with simultaneous presentation would be the total number of black cells within the string (i.e., brightness). With delay, he hypothesized that the major determinant of the RT would be the distribution of runs, since subjects would be unable to encode into memory an impression of brightness. Basically, his findings, with some complications, supported these expectations. The resulting model suggests that both brightness and run information are coded and stored separately.

RICHARD W. HALLER

In addition to having the major responsibility for coordinating cur automated laboratory, Haller has collaborated with Reicher on studies of visual search and on sight reading in music (Reicher, Haller, & Aitken, 1972). This work will be described below under Reicher's contribution.

Under Haller's direction, Michael Hughes completed his Masters Thesis on "Some grammatical effects in immediate recall of sentences" (1970). Hughes found that George Miller's prediction, based on Chomsky's transformational grammar that deleted transformations would be a prominent type of error in recall of sentences was confirmed. Nearly 80% of the syntactic errors in his study were of this type. However, the model proposed by Miller that the various errors would be independent fails to account for the results. Sentences were recalled with fewer errors than Miller's binomial model predicts. Although Hughes rejects Miller's idea that transformations are remembered independently as "footnotes," he still finds that the transformational model still seems to be the most promising candidate for explaining his findings.

DOUGLAS L. HINTZMAN

The bulk of Hintzman's research since he joined our project in June, 1969 has dealt with the possibility that during memory subject's lay down multiple memory traces (Hintzman & Waters, 1969, 1970; Hintzman, 1970; Hintzman & Block, 1970, 1971). He has been developing an approach he calls the method of memory judgments. Based upon the usual measures of accuracy of recall, many models assume that frequency of exposure can be equated with strength of memory trace. Hintzman's experiments seem to indicate that each occurrence of a given stimulus item is stored as a separate trace--tagged by when and where it occurred--rather than stored in a single address for duplicates of this item. The strong implication of these findings is that frequency is stored as a separate attribute and does not add to the so-called "strength" of a given item in memory.

GERALD M. REICHER

Reicher's early work on our project dealt with perceptual recognition as a function of meaningfulness of stimulus material (Reicher, 1969) and with the roles of similarity and repetition in memory (Reicher, Ligon, & Conrad, 1969). Both these themes have been followed up by Reicher to investigate the role of highly learned units in increasing efficiency of processing and in making memory more efficient. Much of this work is still either unfinished or in preparation. The study of sight readers in collaboration with Haller (Reicher, Haller, & Aitken, 1972) was initiated to study coding systems at a rather high level of learned organization and mastery. The point of departure was Adrian deGroot's findings about the ability of chess masters to seemingly grasp the complexities of a chess game after an exposure of a few seconds--an exposure time far too small to convey much to experienced but not so accomplished chess players. DeGroot found no overlap in this ability between grandmasters and submasters. This amazing difference could not be attributed to a general difference in visual memory because it disappeared entirely when the pieces on the board were arranged randomly rather than in accord with the positions of an actual game. In some sense, the grandmasters have learned how to take advantage of recurring themes in chess games and code a given situation in terms of a general schema and local "corrections."

Haller and Reicher saw the opportunity to study the same type of superiority among musicians who differ qualitatively and quantitatively in their ability to immediately "sight read" a new piece of music. They found, in agreement with deGroot's results, that the superior sight readers could essentially reproduce, after a brief exposure, an entire line of music with hardly an error. But when the notes were randomly arranged, rather than taken from compositions, the superiority of the good sight readers disappeared. This superiority, it was further demonstrated, was not due to better guessing habits on the part of the good sight readers. Haller and Reicher believe that direct visual to motor coding may be taking place for the accomplished sight readers, whereas the mediocre readers cannot bypass the central, information processing system.

Under Reicher's direction, Richard A. Block completed his Masters Thesis on "The effects of cues to forget in short-term memory tasks" (Block, 1970, 1971). Block, using both proactive and retroactive inhibition paradigms, examined three different hypotheses about the role of cues to forget: (1) they result in erasing the to-be-forgotten material, (2) they enable subjects to rehearse the to-be-remembered material more effectively, or (3) they differentially tag or code the to-be-remembered and to-be-forgotten material. The findings clearly rejected the first two hypotheses and they support the last hypothesis by default. The last hypothesis will need considerable elaboration and sharpening before it can serve as something more than a convenient catch-all.

Also under Reicher's direction, Charles R. R. Snyder completed his Masters Thesis on "Familiarity and processes of visual search," 1970. Snyder began with the assumption that visual processing, in the search paradigm, can be divided into two functional stages of <u>selection</u> and <u>inspection</u>. This distinction parallels that made by other investigators

between "locating" a stimulus object as opposed to "identifying" it. His subjects had to identify a single cued letter from a tachistoscopically presented circular array of twelve letters. The cue (mutilation, color, or inversion) was known in advance, and subjects had to resport the name and position of the cued letter. He found that letters which were adjacent to cued items were incorrectly reported more frequently than letters which were not. These findings strongly suggest that the subjects process where the item is independently from what it is.

Snyder has been working on his doctoral dissertation under the supervision of Michael Posner. He is studying the role of controlability of imagery, as contrasted with the vividness of imagery, in problem solving. In his initial experiments he found that individual differences in ability to mentally rotate Roger Shepard's figures does correlate with ability to solve certain types of puzzles which involve manipulation in three dimensional space. he is still conducting these experiments which, we assume, will soon be finished.

BENSON SCHAEFFER

Schaeffer has effectively adapted the subtractive and chronometric methods of Posner to the study of how semantic memory is organized (Schaeffer & Wallace, 1969, 1970, 1970). In one study he found that when subjects are asked to make same-different judgments on the basis of one particular category, animate versus inanimate, they were influenced by other semantic features of the stimulus. For example, it is easier to say "same" to "rose - daisy" than to "rose - bird," presumably because the former pair has another basis of commonality in the superordinate "flower." Semantic similarity also makes it difficult to call two words different. It seems as if semantic information not demanded by the task is influencing the subject's judgment. According to Schaeffer's model, this effect is due to the subjects having to retrieve and compare superordinate category information rather than due to stimulus similarity as such. The effect disappears when instances of categories are compared directly with category names (i.e., it is no more difficult to respond differently to "wren - mammal" (common category animal) than to "wren-flower"). Schaeffer argues that the effect is due to automatic associative processes rather than information processing strategy because when he gives the subject another task which presumably limits his ability to generate categories, the effect is not reduced. Schaeffer is continuing this work with the goal of developing a theory about the organization of memory, retrieval processes, and comprehension.

Under Schaeffer's direction, Richard J. Wallace completed his Masters Thesis on "S-R compatibility: evidence concerning underlying processes." (1970, 1971). His subjects pressed one of two keys placed to their left or right when one of two stimuli were presented. A stimulus could occur on the left or right, or above or below a fixation point. The subjects performed with their hands uncrossed or crossed. Compatibility effects were found to hold between the position of the stimulus (left or right) and that of the response key, whether or not the hands were crossed. Thus, the effects did not depend on the relation between a stimulus and a particular motor output. Wallace hypothesized that the positions of both the stimulus and the responding hand were related to a spatial code, and the outcome of a comparison between their representations in this code was responsible for the differences in compatibility.

WAYNE A. WICKELGREN

Since he joined our project in August, 1969, Wickelgren has concentrated upon developing a mathematical theory of consolidation in long-term memory. He has found support for the theory in his own experiments as well as previous findings in experimental psychology, neurology, and physiological psychology. The theory states that the period of active study establishes a short-term memory trace and a separate independent long-term trace. The short-term trace is consolidated immediately or almost immediately, so it is available for mediating recall or recognition within tenths of a second or a second or two at most after the study period. The active study period establishes a potential long-term memory trace, but this potential trace cannot contribute to recall or recognition until it is consolidated into a retrievable trace. Consolidation of long-term memory begins to produce a retrievable trace at about 10 seconds after the end of the study period and is essentially at assymptote by around 30 seconds. Wickelgren now believes that he has data to indicate that the single retention function can be used to describe the retention for all delays from a minute to two years.

HENRY K. BELLER

Dr. Beller (now at the State University of New York, Brockport) was our Visiting Scholar during the second two years of our project. During his stay with us, Beller successfully combined the approach and concepts from the Neisser visual search paradigm with the concepts and methodology of Posner's matching paradigm. The first example of this approach (Beller, 1970) tested Neisser's two-stage model of recognition in the matching paradigm. Evidence of parallel processing was obtained in an experiment where subjects could respond _same_ as quickly to eight identical letters as to two identical letters. But evidence for a subsequent serial stage was obtained in another experiment in which subjects matched letters of uppercase and lowercase and the number of letters differing in case was increased. Beller did find some apparent discrepancies from Neisser's model which he resolved by assuming that the first stage of processing has to segment stimuli.

Beller used a modification of Posner and Mitchell's chronometric paradigm to clarify the role of advance information on matching (Beller, 1971). The subjects were shown in advance one of a pair of letters to be matched. This advance information (prime) shortened reaction time to physical matches even when the case of the prime was ambiguous. Priming facilitated name matches even more than physical matches, but only when name code matching was mandatory. Beller interprets these results as suggesting that priming affects information processing at two levels, stimulus encoding and memory access.

3.3. Human Performance

This area includes Steven Keele, Michael I. Posner and our Visiting Scholar, Carlo Umilta.

STEVEN W. KEELE

The variety of focii for the research by Keele--attention, human performance, memory storage, memory retrieval, movement control, motor skills, repetition effects, automation, pattern recognition, environmental stress--all are generated by the single central theme that human performance is largely a matter of man's limitations in memory storage, memory retrieval, and movement control. Both he and Posner have been elaborating and refining a theory--closely buttressed by the large accumulation of experimental results by themselves, their students, the other investigators on this project, and the work of closely affiliated laboratories--based on the fact that man's difficulties in processing information take two forms: limitations of time and limitations of attention (Posner & Keele, 1972).

Over the span of the four years of the project, Keele's integrative role has emerged in two key works. The first was the review article on movement control in skilled motor performance (Keele, 1969). In that article, Keele marshalled the evidence to demonstrate that the relation between speed, accuracy, and distance of a movement is determined by time to process feedback and make corrective alterations in the movement. In that same article, Keele points out how the study of movements is relevant to understanding of perceptual and memory skills as well as motor skills. The second work is a book on attention and human performance which Keele is just completing. Around the three basic components of storage, retrieval, and movement Keele provides an integrative summary of much of the work that we have accomplished during the period of this contract.

Keele's paper on the repetition effect (Keele, 1969) suggested that the repetition effect was due to stimulus anticipation and the saving in memory search time with correct anticipations. This idea was one of the points of departure for the work on repetition done by our second Visiting Scholar, Carol Umilta, which we will describe below.

In his experiments on the effects of input and output modes on decision time (Keele, 1970), Keele studied rapid decision making about stimuli composed of values on single attributes and stimuli composed of compounds of more than one attribute. In one experiment, he demonstrated that for a fixed number of unitary stimuli, reducing the number of response categories into which the stimuli were mapped results in a decrease in reaction time. But for compound stimuli such information reduction did not result in comparable decreases in time. A memory retrieval model seems to account for these results. A second experiment focussed upon the output mode. He found that decision time was much less when a unitary response was made to a compound stimulus than when separate responses were made to the components. This latter result supports the theory that attentional limitations are due primarily to response conflict rather than inability to process stimuli simultaneously.

In his most recent study (Keele, 1972) he focussed upon the attention demands of memory retrieval. To determine whether the retrieval stage demands attention, two sources of information, form and color, were simultaneously presented. Only color was relevant to the key-pressing response. When the irrelevant form spelled a word, such as GLASS, no interference with processing the relevant color was found. Yet it was concluded that the irrelevant information had contacted memory because when the word meaning was changed, such as to GREEN, the time to respond to the color of ink increased. A discrimination of meaning must depend on information stored in memory. The evidence supports the view that memory retrieval is a non-attentive process; more than one source of information can contact memory at a time.

Jerry G. Ells (now at the University of Calgary) completed under Keele's supervision his doctoral dissertation on "Attentional requirements of movement control " (1969). He used the probe technique as developed by Posner and Keele. By this means he assessed the attentional demands of the decision preceding the movement, the movement itself, and the period of time immediately after hitting the target. During the decision phase, he discovered, the delay in reacting to the probe is affected only by the number of alternative movements available and not by the difficulty of the movement itself. Once the movement has begun, the decision difficulty has no further influence, and probe delay is influenced only by the required accuracy of the movement.

Another doctoral dissertation under Keele's supervision was completed by Gerald J. Laabs (now at the University of York) on "Cue effects in motor short-term memory" (1971). Laabs started with the observation that despite a proliferating number of studies on short-term memory and simple motor acts, the picture was confused with contradictory results. He felt that not enough attention was being given to cues that subjects actually use in making their responses. He chose to focus upon two of the most prominent cues in studies of motor memory: movement location and movement distance. His findings, in agreement with earlier work of Posner, clearly indicate separate memory functions for location information and distance information when used as cues in movement reproduction. Laabs elaborated a model to account for these findings.

Steve Buggie completed under Keele's supervision his Masters Thesis on "Stimulus proprocessing and abstraction in the recognition of disoriented forms" (1970). Buggie investigated the effects of phenomenal disorientation of letter pairs on different levels of processing during recognition and classification. Rotating a letter adds a constant to mean reaction times for matches made at either the physical or name code levels. This suggests that the visual operation which compensates for rotary disorientation is a stage which proceeds either visual or name identity matches. But this stage is not entirely free from the effects of familiarity as Buggie discovered in a second experiment. One conclusion is that the abstraction of the name codes from disoriented letters may have a dual basis: first, the image of a rotated letter may be actively refined by a time consuming compensatory operation such as mentally rotating the image to its familiar orientation and then extracting its name (this conclusion in part, has been independently verified in a striking manner by Roger Shepard at Stanford). Another basis is that

some characters possess discriminable rotation-free features which permit direct identification without going through the mental manipulation or preprocessing (this latter basis could represent the effects of familiarity).

Jock Schwank (now at the Air Force Academy) whose Master's Thesis on "Design parameters for Oregon ballots" (1971) was also completed under Keele's supervision, undertook to apply principles of human performance to the task of designing a more efficient format for election ballots in Oregon primary elections. His experimental analysis came up with several specific suggestions for redesigning the ballot. Schwank also carried some of Keele's interests in studying various forms of stress upon work performance into an experiment on the effect of the menstrual cycle on performance of various laboratory tasks. He was able to find no significant performance decrements due to menstrual cycle for card sorting, time estimation, or a 30-minute, highly compatible, key pressing task.

Because, more than any of the other investigators on this contract, Posner has concentrated upon systematically and experimentally pinning down all the steps that occur between stimulation and response, his work has been central to the other projects. In one way or another just about all the work done by the other investigators has relied heavily upon the paradigms, methods, and themes emerging from Posner's program to trace out the various stages of processing from sensory analysis through organization and retrieval from memory and finally culminating in overt responding. Much of Posner's work on this contract can be organized around the question: What happens between the onset of a physical stimulus object (such as the letter "A") and the subsequent response that the subject makes to this stimulus? By ingenious experimental arrangements, Posner and his students have isolated processes and components that occur at various stages between the onset of the stimulus and the eventual reaction. One stage is the sensory analysis that must take place prior to contact with memory or any form of identification. Another stage is the result of contact with memory which results in some form of identification or recognition. A higher stage might be the classification of the stimulus object in terms of superordinate categories (Is it a letter or a digit? Is it a vowel or a consonant?). A still higher order stage is in terms of output that has to result from some transformation applied to the stimulus (What is the letter which immediately precedes this one in the alphabet?). And finally comes the response which might range from matching, identification, recognition, execution of some task, etc. The spelling out of such stages in a linear sequence is a convenience of exposition only. The facts argue strongly that such stages exist in relative independence, but overlap in time. One question in this program concerns the extent to which such overlap in processes necessarily occurs and the extent to which some of these stages can be bypassed or eliminated in certain kinds of tasks (especially highly skilled ones).

Some of the important questions that have been and are being tackled within Posner's program are: 1) to what extent can we operationally separate the visual processing from the naming (identification) stages? The answer, contained in a number of complementary studies done under the contract, is that we can separate and manipulate these two stages quite independently (Cf., e.g., Posner, Boies, Eichelman, & Taylor, 1969). This achievement has been one of the outstanding successes of the project. 2) Does familiarity affect the visual process? This is the old question about the extent to which primitive perceptual processing can be altered by experience, expectations and familiarity. This has been a surprisingly intractable problem. Whenever an experimental psychologist has seemingly demonstrated a clear effect of familiarity upon perception, later work and criticism has been able to explain the effect away as due to response factors rather than perceptual. At first the findings in our laboratory seemed to suggest that familiarity could operate only in the processing of large complex perceptual material. But now there is newer evidence to suggest that familiarity can operate much earlier in the perceptual intake than was previously supposed. Just how much and how soon is still an open question. It still is true, however, that much of what we consider to be the effects of familiarity occurs only after stimulus input has made contact with memory. 3) Are visual (physical) processes and

naming processes sequential or parallel? The answer seems to be that they operate in parallel but with different time courses. 4) Can subjects generate a visual image from a symbolic or verbal descriptor? When the early work by Posner and his students under this contract was undertaken, most experimental psychologists were dubious. But now, as Posner and his colleagues have demonstrated (Cf., Posner et al., 1969), the ability to generate visual images is considered to be another hard-nosed fact that can be documented by laboratory methods. 5) Do logical superordinates require that the subject first retrieve the name of the object? For example, in classifying a given letter as a voweel or a consonant does the subject first have to identify its name? The answer, as Posner has shown (Posner, 1970), seems to be that subjects do first identify the name of the letter before they classify it as a vowel or a consonant (this does not necessarily mean that they "must" so identify it). On the other hand, the evidence is just as clear that they do not have to identify a stimulus by its name in order to classify it as a letter or a number. The next question is whether the cases in which subjects apparently do go through an intermediate stage is obligatory or can be eliminated.

The big question is where does consciousness enter the picture in this series of stages of processing? Posner has developed operational means for indexing consciousness within this experimental paradigms. One may, of course, object to Posner's particular definition of consciousness, but there is no question that what he calls by that name is being dealt with in objective terms. In fact, consciousness as a construct has entered these experiments via two separate connotations: that of "intention" and that of central processing capacity. The first connotation is based upon the question of whether subjects are obligated to employ a certain stage or is it optional during a more complex operation. The second connotation leads to the experimental treatment as "unconscious" those processes which can operate without any demonstrable interference with a task that is known to occupy the central processor (Cf., e.g., the paper by Posner and Keele, Time and space as measures of mental operations, 1970). Within this context, one question has been: How complex an operation can be carried out without the involvement of consciousness? This involves the issue of the extent to which complex skills can be executed without interfering with other tasks that obviously use conscious attention. A second question is at what level can consciousness be inserted into a complex operation. To what extent, that is, can an individual redirect his conscious, attentional resources to various stages of the processing?

In addition to having studied the preceding questions with the probe techniques, matching paradigms and other experimental arrangements that he developed during this contract, Posner has been perfecting and applying the methodology for indexing the physiological substrata of component processes by means of EEG's, especially the evoked potential. For this purpose, under the contract, we have built analog-to-digital converters and have incorporated the physiological recording and analysis as another component of our automated laboratory. Results of experiments carried out with this new set up indicate, for example, that visual processing of a stimulus object can occur without "consciousness", but that the decision to perform a specific act in response to the stimulus apparently does involve consciousness.

For his doctoral dissertation, Warren devised an ingenious technique for demonstrating the unwanted, and perhaps obligatory, role of higher order processing in dealing with an essentially lower order task. In brief, the subject might be given a set of three words such as "flower, tree, vegetable." He is told to hold these in memory in order to be tested on them later after an intervening task. One possibility is that the very act of holding these three words in memory will automatically also activate the superordinate category name "plant." To test this, the intervening task might present the subject with the word "plant" printed, say, in blue ink. The subject's task is simply to name the color of the ink. In such a case, Warren found that if the name of the word was related to those in memory, say by a superordinate relation, then the subject's time to name the color of the ink in which the word was printed was elevated in comparison with control words that were not so related. Warren included a variety of control comparisons to make sure that this effect was not an artifact. In Posner's terms, this result represents an example where consciousness enters the picture to create interference although it is completely irrelevant to the task. The question that is now raised is whether the subject can be taught to handle such a task without interference from consciousness.

Joe L. Lewis (now at the University of Texas, Arlington) completed under Posner's supervision his doctoral dissertation on "Activation of 'logogens' in an audio-visual word task" (1970). In some earlier work on the project (Lewis, 1970) using dichotic listening, Lewis found evidence that unattended information is processed at the semantic level. Because of the possibility that ears may be unique as information channels, Lewis decided to investigate a bimodal form of presentation of the messages--one audio and one visual. He again obtained results revealing interference in naming attended words when semantically similar words were presented in an unattended message. But the effect was observed only when audio was attended with visual unattended. A series of further experiments was conducted to clarify the locus of interference or facilitation which occurs during dual sensory input. Again interference was observed only when the unattended word was audio and was simultaneous with, or lagged the attended word. This was attributed to specific interference with the verbal output. Lewis discusses the results in terms of a two stage model. The stages are stimulus encoding and response selection. Facilitation effects, suggests Lewis, are generally due to enhancement of the encoding function while interference is primarily due to response competition.

Lewis served, in a postdoctoral capacity, as the director of our automated laboratory during the last year of the project. In that capacity he made important contributions to its functioning, especially in the developing of our time-sharing system (Cf., Lewis, Boies, & Osgood, 1971; other papers in preparation).

Stephen J. Boies (now at International Business Machines, Yorktown Heights) completed under Posner's direction both his Masters thesis on "Retention of visual information from a single letter" (1969) and his doctoral dissertation on "Memory codes in a speeded classification task" (1971). In his MA thesis Boies explored the conditions for rehearsal and generation of visual information. He showed that concentration upon the visual form can lead to improved matching out to two seconds. However, this appears to be quite difficult for subjects, either because the system

which mediates this activity fatigues, or because a lapse of attention leads to a loss of the visual representation from a readily accessible store. Boies followed up on these findings in his doctoral dissertation. He attempted to examine the memory codes which are used when the subject is asked to classify two letters as being the same or different. His first two experiments explored the subject's ability to generate a visual representation of a stimulus from the name of the stimulus. The third experiment investigated the similarity between the search characteristics of generated visual information and information which is abstracted from a visually presented stimulus. The fourth experiment explored the role of practice in the matching task. The final two experiments examined the role of processing capacity inthe process of generation. In brief, Boies' overall findings are taken to support the generation hypothesis. When two letters are to be matched, the longer the interval between the onset of the first letter and that of the second, the less the relative advantage of a match based on physical identity as opposed to name identity. The original interpretation of this result was that the memory trace for the physical code fades and the subsequent match has to depend upon the name code. Boies found, however, that this loss of advantage for the physical match also occurred if the first letter remained visible during the entire interval prior to onset of the second letter. Boies uses his experiments to argue that what actually happens during the interval is that the subject generates the opposite case of that in which the first letter has been shown. He then makes a physical match when the second letter occurs, but one in which he now has two stored representations with which to compare it. Hence, the resulting increment in time to make a physical match is not because the subject has switched to a name code, but because he has had time to generate more than one physical code.

Boies was very instrumental in helping us to develop the Automated Laboratory during our first two years with it.

Under Posner's supervision, Carol Conrad completed her Masters Thesis on "An analysis of a hierarchical model of semantic memory organization" (1971). Conrad investigated the boundary conditions of the theory of semantic memory organization proposed by Collins and Quillian. Their theory suggests that semantic memory is organized into a network of inclusive, ordered hierarchies which include superordinate or category names and properties which uniquely define these categories. The theory also implies that this organization is based on cognitive economy--no property may appear more than once in the system. Her first experiment suggests that the positive results obtained by Collins and Quillian in support of their theory may have resulted from a failure to control for the frequency with which a property is assigned to its presumed category in memory. Her findings suggest that properties may be stored in memory with every category with which they are highly associated. When these findings are combined with those from her second experiment they suggest that the notion of cognitive economy does not accurately describe the organization of semantic memory; they do suggest that words in memory are directly defined by all properties which have been highly associated with these words in the past. During the last year of the contract, Conrad began work on her doctoral dissertation which will investigate waysof disambiguating sentences.

Elaine Turnbull completed under Posner's direction her Masters Thesis on "Visual and name processes in a visual search task" (1971). Turnbull wanted to see if the often repeated finding of Posner and his students that physical matches take less time than name matches could generalize to paradigms other than the original letter-matching one. In particular, she used Neisser's visual search paradigm as another place to study this separation of matching processes. In her first experiment, she wanted to see if there was some advantage of searching for two targets which are physically different but have the same name (say A and a) as compared with searching for two targets which are physically different but have different names (say A and b). She found, in fact, that this was the case. However, the advantage was never as great as having the single target that did not vary in physical form. The results suggested the possibility that subjects were storing and actively rehearsing an auditory name code during the search. Accordingly, a second experiment was conducted to investigate this possibility. The idea was to see if simultaneous auditory input from an external source would interfere with the search task, especially as the input increased in similarity to the rehearsed name. Such interference was not obtained. The failure of auditorally presented letter names to degrade visual scanning performance does not prove the absence of name information during the search process. But it does suggest that the name information is not in acoustic form. Turnbull suggests a couple of models which would account for these results.

CARLO A. UMILTA

Dr. Umilta was our second Visiting Scholar. Dr. Umilta, who is from the University of Bologna in Italy, spent the last year of the project with us. During that time he completed two important studies for us, both of which are now in press (Umilta & Snyder, 1972; Umilta, Frost, & Hyman, 1972). One study, on the repetition effect continues some work that Hyman and Umilta began when Hyman was a Fulbright-Hays Scholar at the University of Bologna in 1967-68. In reaction time studies it has been found that RTs for repeated events may be faster (positive recency effect, or repetition effect) or slower (negative recency effect) than RTs for non-repeated events. Umilta and Snyder (Umilta, Snyder, & Snyder, 1972) investigated how the positive and negative recency effects vary with: (a) the event uncertainty; (b) the delay between a response and the next stimulus (RSI); (c) the rank order of the event in a sequence of equivalent events. They found that: (a) under the conditions of their study there is either a positive recency effect or no effect al all; (b) the effect is larger when uncertainty is greater; (c) the effect diminishes as RSI increases; (d) the effect is larger at the beginning than at the end of a sequence of equivalent events when uncertainty is low, while the opposite is true when event uncertainty is high.

The other study (Umilta, Frost, & Hyman, 1972) also relates back to work that Umilta and Hyman in collaboration with others began at the University of Bologna. This work is concerned with hemispheric differences in processing semantic and perceptual input. In one experiment subjects saw letters presented either to the right or left of a central fixation mark. The subjects pressed a key when those stimuli designated as positive appeared, and did not respond to the others. Both right and left hand responding were used. The results indicated a nonsignificant left hemifield (right hemisphere) superiority with one letter, and significantly faster responding to right hemifield presentations for two- and three-letter displays. In a second experiment, subjects responded to single letters, differing simultaneously in visual and phonemic discrimination. Reaction times were interpreted as indicating faster phonemic discriminations of vowel and stop consonant sounds for left and right hemifields, respectively.

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Buggie, S. Processing of sensory and name codes during the matching of disoriented letters. Paper presented at WPA (1971).

Conrad, C. Cognitive economy in semantic memory. Paper presented at WPA (1971).

Corrigan, B. Constant error in the perceptual extrapolation of straight lines. Paper presented at WPA (1970).

Frost, R., & Snyder, C. Stimulus localization and attention. Paper presented at WPA (1970).

Hintzman, D. L. Memory for repetitions and modality. Talk given at Verbal Learning Conference, Lake Arrowhead, California, June, 1971.

Keele, S. W. Psychology and population: What can be taught. Paper presented at WPA (1970).

Keele, S. W. Controlling U. S. population growth. Invited address at WPA (1971).

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Posner, M. I. Visual and name codes of single letters. Colloquim, Stanford University, February, 1968. Psycholinguistics Colloquim, University of Texas, February, 1968. Colloquium, Carnegie Mellon University, April, 1968. Colloquium, Pennsylvania State University, April, 1968.

Posner, M. I. Human information processing. Short course in engineering psychology, University of Michigan, July, 1968.

Posner, M. I. Abstraction and the process of recognition. Series of lectures, State University of New York, July, 1968.

Posner, M. I. Attention demands of movements. International Congress of Applied Psychology, Symposium on Work and Fatigue, Amsterdam, August, 1968.

Posner, M. I. Subtractive method applied to separation of visual and name codes. Symposium honoring Donders, Eindhoven, The Netherlands, August, 1968.

Posner, M. I. Retention of visual and name codes of letters. Colloquium, University of Sussex, October, 1968. Colloquium, Applied Psychology Unit, Cambridge, October, 1968. Colloquium, University of Dundee, Scotland, November, 1968. Colloquium, Reading University, November, 1968. Colloquium, Durham University, January, 1969.

Posner, M. I. Motor control. Talk delivered to Psychological Society, University of Dundee, Scotland November 1968.

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Posner, M. I. Attention and the control of movement. Address of the Psychological Society, University of Cambridge, February 1969. Colloquium, Hull University, February 1969. Colloquium, Sheffield University, March 1969. University of Brussels, Colloquium, April, 1969.

Posner, M. I. Short term memory and human information processing. Colloquium, University of Technology, Loughdorough, England. 1969.

Posner, M. I. Studies of the process of recognition. Colloquium, Oxford University, March 1969.

Posner, M. I. Attention and the control of motor movements. Colloquium, University of Brussels, April 1969.

Posner, M. I. Does preparation require processing capacity? Colloquium, APRU, Cambridge, May 1969.

Posner, M. I. Measurement of internal sensory-motor processes. Neuropsychology, Queen Square Hospital, London, May 1969.

Posner, M. I. Serial and parallel process in the nervous system. University of Aberdeen, Scotland, May 1969.

Posner, M. I. Separating levels of processing of visual information. Symposium on visual information processing, Mathematical Psychological Meetings, Ann Arbor, August 1969.

Posner, M. I., & Wilkinson, R. On the process of preparation. Psychonomics Society, November 1969, St. Louis, Missouri.

Posner, M. I. Natural history of movement control. Invited address, 1st Canadian Symposium on Psychomotor Learning and Sports Psychology, Edmonton, October 1969.

Posner, M. I. Movement control. Colloquium, Emory University, Atlanta, Georgia, January 1970.

Posner, M. I. Components of attention. Colloquium, Stanford University, 1970. Colloquium, University of Waterloo, Queens University, Kingston, Ontario, February 1970. Colloquium, University of Connecticut, Storrs, March 1970. Colloquium, University of Utah, Salt Lake City, April 1970.

Posner, M. I. Attention and information processing. Invited address, WPA (1970).

Posner, M. I. Discussion on hunting the CNV. Symposium, WPA (1970).

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Posner, M. I., & Keele, S. W. Time and space as measures of mental operations. Invited address, APA (1970). Colloquium, University of British Columbia, September 1970.

Posner, M. I. Components of attention. University of British Columbia, 1971. Harvard University, 1971. Rockefeller University, 1971. University of California at San Diego, 1971. Colorado University, 1971. Washington University at St. Louis, 1971. University of California at Los Angeles, 1971.

Posner, M. I., Lewis, J. L., & Conrad, C. Component processes in reading: A performance analysis. Invited address to the Conference on the relationship of speech to learning to read, Baltimore, 1971.

Posner, M. I., & Warren, R. E. Traces, concepts and conscious constructions. The Conference on Coding Processes in Memory, Woods Hole, Massachusetts, August 1971.

Posner, M. I., & Klein, R. On the functions of consciousness. The 4th Meeting on Attention and Performance, Boulder, Colorado, August 1971.

Schaeffer, B. The role of semantic transformations in semantic interference. Paper presented at WPA (1970).

Schaeffer, B. Semantic interference: Obligatory or Optional? Paper presented at WPA (1971).

Snyder, C. R. Selection, inspection and naming in a visual search. Paper presented at WPA (1971).

Stewart, M. R. Memory and absolute judgment. University of Washington & Northern Illinois University, 1969.

Wickelgren, W. Dynamics of memory, Stanford University, December 1969, University of California at Los Angeles & San Diego, 1970.

Wickelgren, W. Trace resistance and the decay of long-term memory. Oklahoma State University, 1971.